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Use of fly ash as partial replacement of sand in concrete

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ABSTRACT

India depends on Thermal Power as its main source, thus increase in power requirement every year. Present scenario of our country shows 75 % of country's total installed power generation is thermal of which coal-based generation is 90%. The coal reserves of the country are predominately of lower grades, non-cooking and as a result more than 110 MT coal ash is being generated every year. Use of coal brings huge amount of ash every year. Ash generation may likely reach to 200 MT by 2015. The current percentage of utilization of fly ash in India is very less as compared to the other countries like Germany, Netherlands etc. The need of fly ash utilization also arises out of the fact that good quality Natural River sand required in concrete and in the cement mortar, is depleting day by day and scarcity of good quality sand is felt by all metro and mega cities in India. Large scale exploitation of natural sand creates environmental impact on society. River sand is most commonly used fine aggregate in concrete but due to acute shortage in

many areas, availability, cost & environmental impact are the major concern. To overcome from this crisis, partial replacement of sand with fly ash can be an economic alternative. Design mix of M20 grade concrete with replacement of 20%, 40% and 60% of fly ash have been considered for laboratory test i.e. slump test and compressive strength. As per M20 Mix Design in this project we have replaced fine aggregate with fly ash. The Concrete specimens have been tested at different age level for Mechanical Properties of concrete, namely, Cube Compressive Strength with other properties such as Slump Cone test, with respect to 7 and 28 Days strength. The main aim of our study is to get economical and eco-friendly concrete.

Keywords: Fly ash, pozzolona, natural sand, concrete

1. INTRODUCTION

It is a pressing need today for the concrete industry to produce concrete with lower environmental impact, the so-called green concrete. This can be achieved in three ways. The first one is by reducing the quantity of cement as one ton of cement saved will save equal amount of CO_2 to be discharged into atmosphere. Secondly by reducing the use of natural aggregates whose resources are limited and are exhausting very fast. It is also achieved by utilizing maximum possible waste materials like fly ash in concrete. This will reduce the requirement of landfill area and make system more sustainable. The World Bank has reported that by 2015 disposal of fly ash will require 1000 square kilometer area or one square meter of land per person. Also SiO_2 and $Al2O_3$ in fly ash react with the free lime available in concrete to form CSH and CAH gel. These gels provide extra cementing material and also fill the pores in concrete making it possible to reduce the quantity of cement.

Fly ash is generally used as replacement of cement, as an admixture in concrete, and in manufacturing of cement. Concrete containing fly ash as partial replacement of cement poses problems of delayed early strength development. Concrete containing fly ash as partial replacement of fine aggregate will have no delayed early strength development, but rather will enhance its workability and strength. This higher workability and strength achieved gives scope for indirectly reducing the cement quantity in concrete. Considering present scope of work only workability, cost and strength properties of concrete were studied. In future durability studies are recommended.

Fine aggregate occupies about 25% to 40% of total volume of concrete and hence provides great opportunity to utilize about 150 kg per m3 waste materials like fly ash for replacement. The need of fly ash utilization also arises out of the fact that good quality Natural River sand required in concrete and in the cement mortar, is depleting day by day and scarcity of good quality sand is felt by all Indian cities.

1.1. Fly Ash and Its Impact

Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. When mixed with lime and water the fly ash forms a cementitious compound with properties very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of cement in the concrete, providing some distinct quality advantages. The concrete is denser resulting in a tighter, smoother surface with less bleeding.

The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 sq.km. of land. Since coal currently accounts for 70% of power production in the country, there is a need of new and innovative methods for reducing impacts on the environment. The problem with fly ash lies in the fact that not only does its disposal require large quantities of land, water and energy, its fine particles, if not managed well, can become airborne. Currently more than 100 million tons of fly ash are being generated annually in India, with 65000 acres of land being occupied by ash ponds. Such a huge quantity dose poses challenging problems, in the form of land use, health hazards and environmental damages.

1.2. Hazards

By virtue of its physical characteristics and sheer volumes generated, fly ash poses problems like:

- It is a very difficult material to handle in dry state because it is very fine and readily airborne even in mild wind.
- It disturbs the ecology of the region, being a source of soil, air and water pollution.
- Long inhalation of fly ash causes silicosis, fibrosis of lungs, bronchitis, pneumonitis etc.
- Flying fine particles of ash poses problems for people living near power stations, corrode structural surfaces and affect horticulture.

Eventual settlement of fly ash particles over many hectares of land in the vicinity of power station brings about perceptible degeneration in soil characteristics.

1.3. Scarcity of Natural Sand

Sand is a major material used for preparation of mortar and concrete and plays a most important role in mix design. In general consumption of natural sand is high, due to the large use of concrete and mortar. Hence the demand of natural sand is very high in developing countries to satisfy the rapid infrastructure growth. The developing country like India facing shortage of good quality natural sand and particularly in India, natural sand deposits are being used up and causing serious threat to environment as well as the society. Together fine and coarse aggregate make about 75-80 % of total volume of concrete and hence it is very important to fine suitable type and good quality aggregate nearby site. Recently natural sand is becoming a very costly material because of its demand in the construction industry due to this condition research began for cheap and easily available alternative material to natural sand. Some alternatives materials have already been used as a replacement of natural sand such as fly-ash, quarry dust or limestone and siliceous stone powder, filtered sand, copper slag are used in concrete and mortar mixtures as a partial or full replacement of natural sand.

Due to shortage of river sand as well as its high the Madras High Court restrictions on sand mining in rivers Cauvery and Tamirabharani. The facts like in India is almost same in others countries also. Researcher and Engineers have come out with their own ideas to decrease or fully replace the use of river sand and use recent innovations such as M-Sand (manufactured sand), robot silica or sand, stone crusher dust, filtered sand, treated and sieved silt removed from reservoirs as well as dams besides sand from other water bodies.

On the other hand, lack in required quality is the major limitation in some of the above materials. Now a day's sustainable infrastructural growth requires the alternative material that should satisfy technical requisites of fine aggregate as well as it should be available locally with large amount.

1.4. Need for Utilization of Flyash

Considering that the Ninth plan (1997-2002) had proposed a pivotal place to thermal power generation it was estimated that it shall increase at an annual rate of around 8-10%. Consequently, fly ash generation shall touch the 100 million ton / year mark by year 2000 & 125 million ton by 2003-2004. The major sources of fly ash production in India are the thermal power units. It is estimated that by the end of the tenth plan period (March 2007) an additional 124000 MW of power sector expansion will be required in India to meet the rising energy demand. Though the state of Orissa is not thickly industrialized, the fly ash generation in the state is to the tune of 93 lakh tones per annum. As far as thermal power sectors in Orissa are concerned about 22.6% of fly ash is being utilized.
Present Scenario on Fly Ash in India:

- Over 73 % of the total installed power generation is thermal
- 230 - 250 million MT coal is being used every year
- High ash contents varying from 30 to 50%
- More than 110 million MT of ash generated every year
- Ash generation likely to reach 170 million MT by 2010
- Presently 65,000 acres of land occupied by ash ponds
- Presently as per the Ministry of Environment & Forest Figures, 30% of Ash is being used in fillings, embankments, construction, block & tiles, etc.

The fly ash produced as a result of burning of Indian coal has tremendous potential to be utilized for different applications. The current percentage of utilization of fly ash in India is very less as compared to the other countries like Germany, Netherlands etc. where the utilization is above 90 %. As nearly 73% of the country's total installed power generation capacity is thermal of which coal-based generation is 90%. Some 85 thermal power stations, besides several captive power plants use bituminous and sub-bituminous coal and produce large quantities of fly ash. High ash content (30% - 50%) coal contributes to these large volumes of fly ash. Thus fly ash management is a major cause of concern for the future.

2. LITERATURE REVIEW

Though number of significant results has been reported on the use of fly ash in concrete, but there is not much literature available on the use of fly ash as partial replacement of fine aggregates.

Wang et al. used recycled mineral admixture such as fly ash, slag, glass sand and rubber powder as replacement of 5% to 10% replacement of fine aggregate in their study of light weight concrete. With their study they reported that slump of the concrete with

mineral admixtures was within design requirement. They also reported that light weight aggregate yielded better hardened properties than normal weight concrete.

Nambiar et al. studied the influence of filler type on the properties of foam concrete. They reported the results of a systematic study to ascertain the influence of filler type (i.e. sand and fly ash) and the particle size of sand on the properties of moist cured foam concrete. Results showed that an increase in fly ash content results in higher strength for a given density, as fly ash is of pozzolanic nature.

Hwang et al. based on their experimental results concerning the compressive strength development of concrete containing fly ash, the authors derived an estimation equation for compressive strength development taking into consideration age of concrete, fly ash content and Blain's specific surface area of fly ash.

Jones et al. made an extensive laboratory based investigation into unprocessed low lime fly ash in foamed concrete as a replacement for sand. It is reported that the strength of fly ash concrete was more than 3 times higher than the sand concrete. More significantly, while the strength of sand mixes remained fairly constant beyond 28 days, those of fly ash foamed concrete at 56 and 180 days were up to 1.7 to 2.5 times higher than 28 days values, respectively.

Rebeiz et al. reported investigation on the use of fly ash as replacement of sand in polymer concrete. The replacement of 15% sand with fly ash by weight increased the compressive strength by about 30%. They also reported good surface finish due to addition of fly ash as replacement of sand which also reduces the permeability and has an attractive dark color.

Siddique carried out experimental investigation to evaluate the mechanical properties of concrete mixes in which fine aggregate (sand) was partially replaced with class F fly ash. Fine aggregate was replaced with 10%, 20%, 30%, 40% and 50% of class F fly ash by weight. The test results showed that the compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of fly ash concrete mixes with 10% to 50% fine aggregate replacement with fly ash showed improvement in the results as compared to control concrete. Replacement of fine aggregate with fly ash resulted in decreasing slump which needed more quantity of super plasticizers to be added to concrete.

Famili et al. studied effect of saturated light weight aggregate on material properties on concrete. They reported that shrinkage of sealed cured specimen containing light weight arrogate was lower than without light weight arrogate concrete.

From the literature reviewed it is clear that in India disposal of fly ash is a big problem. However as reported high volume fly ash concrete lowers compressive strength compared to cement concrete. In all referred literature replacement of sand with fly ash has produced higher strength than normal concrete with sand as fine aggregate. It is further observed that water absorbed by fly ash could also be used for internal curing of concrete, which may further reduce cracking.

3. MATERIALS & METHODS

3.1. Materials

3.1.1 Cement

Portland slag cement (43 grade) was used. It was tested as per Indian Standard Specifications IS: 8112-1989.

3.1.2. Bottom ash

The fly ash sample was collected from near the hopper of the power plant from Captive Power Plant - I of Rourkela steel Plant. The fly ash sample collected was dark grey in color. It was tested as per BIS 1727:1967 and results are given in Table 1.Its specific gravity is found to be 2.46.

Table 1 Chemical Analysis of Bottom Ash

Silicon dioxide (SiO_2)	55.5
Aluminium oxide (Al_2O_3)	31.3
Ferric oxide (Fe_2O_3)	6.4
Calcium oxide (CaO)	1.02
Magnesium oxide (MgO)	0.21
Titanium oxide (TiO_2)	2.7
Sulphur trioxide (SO_3)	0.44
Loss on ignition	0.74

3.1.3. Fine Aggregate

Natural sand passing through 10 mm sieve was used as a fine aggregate. It was tested as per Indian Standard Specifications BIS: 383-1970. Sand was conforming to Zone II. Its sieve analysis and physical property is shown in Table 2 and Table 3 respectively.

3.1.4. Coarse Aggregate

Coarse aggregate used in this study were 20-mm nominal size, and were tested as per Indian Standard Specifications IS: 383-1970. Coarse aggregates passing 40 mm and 12.5 mm sieves were combined (60:40).

Table 2 Sieve Analysis of Fine Aggregate

BIS sieve size	Sand % cumulative	Sand % finer
10mm	0	100
4.75mm	1.103	98.897
2.36mm	2.106	97.894
1.18mm	10.632	89.368
600 µ	60.281	39.719
300µ	87.964	12.036
150 µ	100	0

Table 3 Physical properties of aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.49	2.82
Water Absorption%	0.35	0.37

3.2. Mix Proportions

Four mixture proportions of M20 were made. First was control mix (without fly ash), and the other three mixes contained Class F bottom ash. Design mix used was 1:1.77:3.24. Fine aggregate (sand) was replaced with fly ash by weight. The proportions of fine aggregate replaced ranged from 20% to 60%. Mix proportions are given in Table 4. The control mix M20 without fly ash was proportioned as per Indian Standard Specifications IS: 10262-2009, to obtain a 28-day cube compressive strength of 26.6 MPa. Concrete mixes were made in power-driven revolving type drum mixers.

Table 4 Mix proportions of concrete

Mixture No.	M-1	M-2	M-3	M-4
Cement(kg/m3)	8.87	8.87	8.87	8.87
Fly ash %	0	20	40	60
Fly ash(kg/m3)	0	3.14	6.28	9.42
W/C	0.5	0.5	0.5	0.5
Water	4.44	4.44	4.44	4.44
Sand (kg/m3)	15.7	12.56	9.42	6.28
Coarse Aggregate(kg/m3)	29.01	29.01	29.01	29.01
Slump (mm)	26	21	18	15
No. of cubes	6	6	6	6

3.3. Preparation and Casting of Test Specimens

All the cubes and beams were vibrated on vibration table. After casting, all the test specimens were finished with a steel trowel. They were de molded after 24 hours and were put into a water-curing tank at standard temperature 27˚C ± 2˚C. Numbers of specimens cast for each mix are given in Table 4. Experimental program was designed to understand the effect of partial replacement of sand with fly ash on important concrete properties like workability and strength. To know effect of Workability slump cone was calculated. Compressive strength was investigated to study effect on strength which is needed for design of various structures.

3.4. Fresh Concrete Properties

Fresh concrete properties such as slump and unit weight was determined according to Indian Standard Specifications IS: 1199-1959. The results are presented in Table 4.

3.5. Hardened Concrete Properties

The 150-mm concrete cubes were tested for compressive strength on seventh and twenty eighth day. The results are given in Table 5.

Table 5 Compressive Strength of Concrete

Mix	Description	Compressive Strength	
		7 Days	28 Days
M-1	No Fly Ash	18.66	35.67
M-2	20%	20.45	47.83
M-3	40%	23.54	48.15
M-4	60%	19.22	35.12

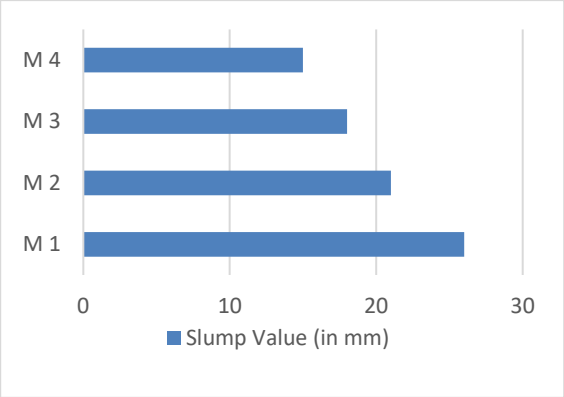

Figure 1 Comparison of slump

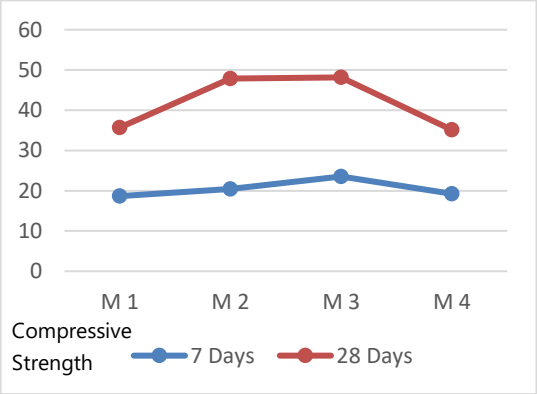

Figure 2 Compressive Strength of Concrete

4. CONCLUSION

The following conclusions could be drawn from the present investigation:

- The workability for fly ash concrete decreases when compared with sand concrete as clear from the graph shown in figure 1.
- The compressive strength increase with increase in fly ash percentage in the concrete mix up to 40% and decreases for 60% as shown in figure 2.
- The replacement of sand with fly ash up to 40% is beneficial for the concrete works.
- It is economical, eco-friendly and can prove to be a boon for developing countries like India where there is over exploitation of natural resources at such a large scale.
- This study could not only enlighten the local people but also to the contractors to use bottom ash to replace sand for concrete works.
- It can lead to a revolution in the field of Sustainable environmental Management.

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